

"INVESTIGATION INTO THE NATURE
OF EMULSIFIED ASPHALTS COMPATIBLE
WITH CALIFORNIA LOCAL AGGREGATES
AND SUBSTITUTION OF SULFUR FOR
ASPHALT IN AQUEOUS
EMULSIFIED SYSTEMS"

EXECUTIVE SUMMARY



**WESTERN
TECHNOLOGIES,
INC.**

Phoenix

3737 East Broadway Road
P.O. Box 21387
Phoenix, Arizona 85036
(602) 268-1381

Flagstaff

2400 East Huntington Drive
Flagstaff, Arizona 86001
(602) 774-8708

Tucson

423 South Olsen Avenue
Tucson, Arizona 85719
(602) 624-8894

Farmington

400 South Lorena
Farmington, New Mexico 87401
(505) 327-4966

Las Vegas

300 West Boston Avenue
Las Vegas, Nevada 89102
(702) 382-7483

Grand Junction

P.O. Box 177
3224 Highway 6 & 24, No. 3
Clifton, Colorado 81520
(303) 434-9873

EXECUTIVE SUMMARY

"INVESTIGATION INTO THE NATURE OF EMULSIFIED
ASPHALTS COMPATIBLE WITH CALIFORNIA LOCAL
AGGREGATES AND SUBSTITUTION OF SULFUR FOR
ASPHALT IN AQUEOUS EMULSIFIED SYSTEMS"

BY

J. C. ROSNER, J. G. CHEHOVITS

SUBMITTED TO

STATE OF CALIFORNIA
AIR RESOURCES BOARD
1800 - 15th STREET
SACRAMENTO, CALIFORNIA 95814

FOR

RESEARCH PROJECT - A9-142-31

SUBMITTED BY

WESTERN TECHNOLOGIES, INC.
3737 EAST BROADWAY ROAD
PHOENIX, ARIZONA 85040

June, 1982

ABSTRACT

This study investigated the use of solvent free asphalt emulsions and emulsions containing sulfur-extended-asphalt (SEA) as a base stock with low and high quality aggregates from California with the intent of substituting these emulsions for conventional emulsions and cutback asphalts in road construction. Emulsions studied included both cationic slow set and cationic medium set solvent free emulsions, a conventional cationic medium set emulsion which contained 7 percent solvent, and anionic slow setting SEA emulsions with both 15 and 30 percent sulfur-extended-asphalt-base stocks. Aggregates included a high quality crushed granite, a low quality pit run decomposed granite, and a low quality bank run gravel. Each aggregate was processed into a low and high quality level by addition of fines or partial washing.

Two statistically designed experiments were conducted to compare characteristics of paving mixtures containing the solvent free and SEA emulsions to those of the traditional emulsion. Aggregate and emulsion characteristics were determined. Emulsion-aggregate mixture characteristics including coating, stabilometer values, cohesiometer values, resilient modulus, air voids, voids in mineral aggregate, swell, moisture vapor susceptibility and surface abrasion were evaluated. Pavement section designs were performed for the mixtures to permit initial economic comparisons.

The study concluded that the solvent free asphalt and SEA emulsions studied could effectively coat and mix with all aggregates studied and that coatings were better than attained with the conventional emulsion. Stabilometer values in excess of 30 (minimum for Caltrans Type C asphalt concrete) were attained with many of the low quality aggregates with both the solvent free asphalt and SEA emulsions. Mixtures containing the solvent free cationic medium set emulsion were detrimentally affected by water to a greater degree than mixtures with the conventional solvent containing cationic medium set or solvent free cationic slow set emulsions. Mixtures made with the SEA emulsions were detrimentally affected by water to a high degree. Pavement structural designs showed that lesser pavement thicknesses are required when using solvent free or SEA emulsions as compared to conventional emulsions containing solvent. Recommendations are forwarded for additional laboratory work to compare mixture properties with both cutback and hot-mixed asphalts. Field test sections are also recommended.

ACKNOWLEDGEMENTS

Project Personnel

Joseph A. Pantalone	-	Contract Manager, Air Resources Board
Dr. John C. Rosner	-	Principal Investigator Western Technologies, Inc.
James G. Chehovits	-	Secondary Investigator, Western Technologies, Inc.

"This report was submitted in fulfillment of A9-142-31, "Investigation Into The Nature Of Emulsified Asphalts Compatible With California Local Aggregates And Substitution Of Sulfur For Asphalt In Aqueous Emulsified Systems", by Western Technologies, Inc. under the sponsorship of the California Air Resources Board. Work was completed as of April 2, 1982."

DISCLAIMER

"The statements and conclusions in this report are those of the contractor and not necessarily those of the California Air Resources Board. The mention of commercial products, their source or their use in connection with material reported herein is not to be construed as either an actual or implied endorsement of such products."

INDEX

	<u>PAGE NO.</u>
INDEX	i
1.0 INTRODUCTION	1
1.1 Background	1
1.2 Project Objectives	3
1.3 Project Scope	3
1.4 Investigational Procedure	3
2.0 MATERIALS	4
2.1 Aggregates	4
2.2 Aggregate Quality Levels	5
2.3 Asphalt Emulsions	5
2.4 Sulfur-Extended-Asphalt Emulsions	7
3.0 EXPERIMENTAL DESIGN AND DATA ANALYSIS	8
3.1 Asphalt Emulsions	8
3.2 Sulfur-Extended-Asphalt Emulsions	10
4.0 MIXTURE DESIGNS AND SPECIMEN TESTING	11
4.1 Introduction To Procedure	11
4.2 Testing Procedures During The Mixture Design Phase	11
4.3 Mixture Design Calculations	12
4.4 Selection Of Design Emulsion Residue Content.	12
4.5 Tests On Specimens At The Design Residue Content	13
5.0 CONCLUSIONS	13
5.1 Solvent Free Asphalt Emulsions	13
5.2 Sulfur-Extended-Asphalt Emulsions	14
6.0 RECOMMENDATIONS	17
REFERENCES	19

1.0 INTRODUCTION

1.1 Background

Bituminous binders used in pavement construction may be classified into three groupings - asphalt cements, cutback asphalts, and emulsified asphalts. Asphalt cements are generally produced as an end product from the refining of crude oil and are semi-solids at ambient temperature. In order to use asphalt cements in pavement construction, both the aggregate and asphalt cement are heated to between 250 and 325F*. At these temperatures, asphalt cement is relatively fluid and will effectively coat the aggregate when mixed. Mixing is generally accomplished in a central or portable plant. While the mixture is hot (250 to 325F), it may be spread on a prepared base and compacted to form a durable pavement surface. The asphalt cement-aggregate mixture (hot-mixed asphalt concrete) gains strength as it cools to ambient temperature.

During production of hot-mixed asphalt concrete much energy is consumed while heating the asphalt cement and aggregate. In remote areas, and for rather small projects, the requirement of using the central or portable mixing plant may be restrictive. In remote areas, many times, either cutback or emulsified asphalts are used instead of asphalt cements. Cutback asphalt is an asphalt cement which has been liquified by blending with various types of petroleum based solvents. Emulsified asphalts are fluid dispersions of asphalt in water. Both cutback and emulsified asphalts are fluid at ambient temperatures and may readily be mixed with aggregates at ambient temperatures thus offering a potential energy savings when compared to hot-mixed asphalt concrete. The mixtures may be placed and compacted to form a pavement.

Cutback and emulsified asphalts gain strength by evaporation of the fluidizing medium. With cutbacks, petroleum based solvents are evolved and with emulsions, water. It has been estimated that approximately 25,000 tons of solvents are evolved into the atmosphere each year in California from cutback asphalts (1)**. This not only is a major source of hydrocarbon emissions, but is a waste of a non-renewable resource.

Notes:

* All temperatures cited herein are in terms of degrees.

** Numbers in parenthesis indicate reference at end of text.

Addition of solvent to asphalt emulsions has been found to improve the coating ability of the emulsion when used with poor or marginal quality aggregates. Traditional asphalt emulsion formulations may contain up to 12 percent solvent (2). The substitution of traditional emulsified asphalts for cutbacks may reduce hydrocarbon emissions, but the reduction may not be large due to the presence of solvents in the emulsified system. Additionally, use of solvents in emulsions tend to soften the asphalt residue which may result in poorer field performance.

Recently, asphalt emulsions have been developed which can effectively coat marginal or poor quality aggregates without the use of petroleum based solvents. Use of solvent free asphalt emulsions in place of cutback asphalts has been estimated to have the potential of reducing hydrocarbon emissions by approximately 22,000 tons per year in California, an 85 percent reduction (1).

Traditional emulsified asphalts, however, have been found to perform poorly and not be compatible with low quality aggregates, especially aggregate which contain a high amount (greater than 15 to 20 percent) of claylike fines (3). Since aggregates which are locally available for road construction in several sections of California typically may contain high amounts of claylike fines, use of asphalt emulsions with these types of aggregates has not been extensive in California.

Recently considerable research has been performed with the use of sulfur as a partial substitute for asphalt in hot-mix paving applications. Sulfur has been used to extend asphalt cement by as much as 50 percent by weight (4). Paving mixtures containing these sulfur-extended-asphalts (SEA) have been found to have many properties comparable to those of conventional hot-mixed asphalt concretes. However, a major problem which exists when using SEA in paving is that if mixture temperatures exceed approximately 300F, sulfur dioxide (SO_2) and hydrogen sulfide (H_2S) gases can be evolved creating possible health and environmental hazards (5). Use of a water based emulsified SEA binder would permit mixing and compacting of paving mixtures at ambient temperatures thus lessening environmental hazards and increasing the attractiveness of using sulfur as a partial replacement for asphalt.

1.2 Project Objectives

Objectives of this research project are twofold. First, this study investigates the feasibility of using solvent free emulsified asphalts with local, low quality aggregates in California. The second objective is to investigate the feasibility of using water-based sulfur-extended-asphalt emulsions with low quality California local aggregates.

1.3 Project Scope

The study investigated the use of both cationic medium set (CMS) and cationic slow set (CSS) solvent free asphalt emulsions. For comparison purposes, a conventional CMS asphalt emulsion which contains 7 percent solvent is studied. The solvent used was pure distilled reagent grade naptha produced by Varnish Makers and Painters. Aggregates studied are from three different California sources, one, a high quality crushed granite, the second, a low quality bank run material, and the third, a low quality pit run material. Each of the three aggregates was processed into a high and low quality level by partial washing or addition of fines. Thus, a total of 6 aggregate combinations which are representative of many aggregates available in California for pavement construction were studied.

Two sulfur-extended-asphalt emulsions were studied during the second portion of the investigation. These were anionic slow set (SS) emulsions formulated with both a 15 percent SEA binder and a 30 percent SEA binder. Properties of mixtures containing these two emulsions were also studied with the 6 different project aggregates.

1.4 Investigational Procedure

Two statistically designed experiments were conducted to compare characteristics of paving mixtures containing the solvent free and SEA emulsions to those of the traditional emulsion. Aggregate and emulsion characteristics were determined. Emulsion-aggregate mixture characteristics including coating, stabilometer values, cohesiometer values, resilient modulus, air voids, voids in mineral aggregate, swell, moisture vapor susceptibility and surface abrasion were evaluated. Pavement section designs were performed for the mixtures to permit initial economic comparisons.

2.0 MATERIALS

2.1 Aggregates

Three different aggregate sources from California were used in mixtures studied during this investigation. A high quality crushed granite and two low quality local aggregates were studied. The high quality crushed granite was obtained from the Graniterock Quarry at Aromas, California. One low quality aggregate was a pit run material from San Bernardino County. The second is a bank run material from Fresno County. Sufficient material to complete the study was sampled from each source.

San Bernardino. The San Bernardino aggregate was obtained from the Hesperia Landfill pit which is located approximately 30 miles north of San Bernardino, California. This aggregate source is frequently used with slow curing cutback asphalts for road construction, and is representative of low quality local aggregates used in San Bernardino County. During production of cutback asphalt mixtures, the aggregate is processed over 3/4 inch screens to remove oversize fractions.

Fresno. The Fresno aggregate was obtained from the Cantua Creek pit which is located approximately 40 miles southwest of Fresno, California and 20 miles north of Coalinga. This aggregate source is commonly used with medium curing cutback asphalts for road construction and is representative of low quality aggregates used in Fresno County. During production of cutback asphalt mixtures, the aggregate is processed over 1 inch screens to remove oversize material.

Graniterock. The Graniterock aggregate was obtained from the Graniterock Quarry at Aromas, California which is approximately 40 miles south of San Jose. This aggregate is typical of high quality aggregate used in California and is routinely used in production of hot-mixed asphalt concrete.

Three different size fractions of the Graniterock aggregate were obtained. These fractions are designated as 1/2 inch, 1/4 inch, and crusher sand by the producer. The sand equivalent value of the crusher sand is 60 indicating that the fines are high quality crushed rock.

2.2 Aggregate Quality Levels

As stipulated in the project Request for Proposals (1), aggregates to be studied are to be those with sand equivalent values ranging from 20 to 30 and with minus No. 200 (75 μ m) mesh contents between 10 and 25 percent. In order to investigate not only the effects of aggregate type, but also the level of quality of each aggregate, each of the three aggregates being studied was processed into both a "high" and "low" quality level as indicated by sand equivalent value and minus No. 200 mesh content. For purposes of this study, high quality aggregates are defined as those with sand equivalent values of approximately 30 or above and with minus No. 200 mesh contents near 10 percent, while low quality materials have sand equivalents of approximately 20 and minus No. 200 mesh contents between 10 and 20 percent. Methods used to process aggregates into each quality level are discussed below. Properties of each aggregate at each quality level are tabulated in Table 1.

San Bernardino. The San Bernardino "as received" aggregate met criteria for high quality material. Low quality was achieved by adding 8.6 percent pure kaolinite clay.

Fresno. The Fresno "as received" aggregate met criteria for low quality material. The high quality level was achieved by partially washing the fine portion (minus No. 4 mesh) to remove some of the fines.

Graniterock. The high quality level was achieved by using 15 percent of the 1/2 inch product, 30 percent of the 1/4 inch product, and 55 percent of the crusher sand product. The low quality level was achieved by adding 3.6 percent pure kaolinite clay.

2.3 Asphalt Emulsions

Three asphalt emulsions were formulated and tested during this investigation. These emulsions were formulated for the aggregates considered in the study by the Highway Chemical Division of the Armac Company of McCook, Illinois. The emulsions which were formulated were a cationic slow set solvent free emulsion (CSS-0), a cationic medium set solvent

Table 1. GRADATIONS, SAND EQUIVALENT, C.K.E. VALUES,
SURFACE AREA, ZETA POTENTIAL, AND ATTERBERG LIMITS
FOR HIGH AND LOW QUALITY AGGREGATES

Sieve Size	% Passing					
	San Bernardino		Fresno		Graniterock	
	High	Low	High	Low	High	Low
1" (25.0 mm)	100	100	100	100	100	100
3/4" (19.0 mm)	100	100	92	92	100	100
1/2" (12.5 mm)	96	96	82	82	100	100
3/8" (9.5 mm)	93	93	75	75	94	94
1/4" (6.3 mm)	89	90	67	67	83	84
#4 (4.75 mm)	86	87	62	62	69	70
#8 (2.36 mm)	77	79	54	51	51	53
#10 (2.00 mm)	72	74	53	49	47	49
#16 (1.18 mm)	60	63	48	46	37	39
#30 (600 um)	40	45	40	41	26	29
#40 (425 um)	32	37	36	37	22	25
#50 (300 um)	24	30	29	32	15	21
#100 (150 um)	16	23	16	20	13	16
#200 (75 um)	10.3	17.4	7.9	13.4	9.0	12.0
Sand Equivalent	29	18	29	15	60	26
C.K.E.						
¹ ABR	4.6	8.5	5.3	6.7	4.7	6.9
K _C	1.1	1.2	1.0	1.1	1.2	1.2
K _f	0.9	1.5	1.0	1.2	1.1	1.6
² S.A.	57.1	75.9	57.9	66.5	48.4	57.2
³ SA (Nitrogen Absorption) x 10 ³	39.8	57.4	89.8	111.6	13.8	30.7
⁴ Zeta Potential (mv)	-30.6	-30.8	-30.1	-33.7	-30.8	-31.7
Atterberg Limits						
Liquid Limit	22	21	22	22	22	17
Plastic Limit	N.P.	17	N.P.	21	N.P.	15
Plasticity Index	N.P.	4	N.P.	1	N.P.	2

Notes:

- ¹ Approximate Bitumen Ratio
- ² Surface Area (ft²/lb) calculated base on gradation
- ³ Determined by BET Nitrogen absorption by Armak Company, McCook, Illinois. Results are in ft²/lb
- ⁴ Determined by Armak Company using a Zeta Meter manufactured by Zeta Meter, Inc., New York.

free emulsion (CMS-0), and a conventional cationic medium set emulsion which contained 7 percent solvent (CMS-7). The purpose of considering the CMS-7 emulsion was to compare solvent free emulsified asphalts to traditional emulsions which contain solvent.

Base Asphalt. The base asphalt which was used in all asphalt emulsion formulations was an AR4000 asphalt cement produced by the Edgington Oil Company of Long Beach, California and supplied by Sahuaro Petroleum and Asphalt Company of Phoenix, Arizona. Crude from the Los Angeles Basin was used in the manufacture of this asphalt. The asphalt meets all Caltrans requirements for an AR4000 asphalt.

Emulsions. The three asphalt emulsions were produced at the Armak Asphalt Research Laboratory using a Charlotte Colloid Mill. Selection of the specific emulsion formulations for the aggregates studied was based on aggregate gradation, zeta potential, and surface area. Asphalt emulsion formulations for the various aggregates were identical.

The CSS solvent free emulsion meets all Caltrans requirements for a CSS-1h emulsion except for viscosity at 77F (17.7 for the seconds CSS-0 compared to the specification minimum of 20 seconds).

The CMS-0 emulsion meets Caltran requirements for a CMS-2h emulsion and the CMS-7 percent solvent emulsion meets requirements for a CMS-2 emulsion.

2.4 Sulfur-Extended-Asphalt Emulsions

Two different sulfur-extended-asphalt (SEA) emulsions were produced and studied in this investigation. Formulation and production of the experimental SEA emulsions were studied under a separate research contract with the Federal Highway Administration (6). The emulsions considered for purposes of this study were anionic slow set emulsions containing base stocks with a sulfur content below the asphalt saturation level of 20 percent by weight and a sulfur content above the saturation level. Sulfur extensions studied were 15 and 30 percent by weight of the total SEA binder. Cationic emulsions using SEA could not be studied as formulations available were not as stable as anionics (6).

Base Sulfur-Extended-Asphalts. The base asphalt used in producing the SEA emulsion base stocks was a blend of hard and soft asphalt emulsion bases produced by Edgington Oil Company of Long Beach, California. Edgington AR4000 (which was used as the base for the asphalt emulsions used in this study) was not available as the base asphalt for the sulfur-extended-asphalt emulsions. In order to provide a base asphalt similar to that used in asphalt emulsion formulations in this study, two Edgington emulsion base stocks (hard and soft) produced from the same crude source were blended to give an initial absolute viscosity at 140F of 1900 poise which is equivalent to that of the Edgington AR4000 used in the asphalt emulsions. Proportions used in the blend were 90 percent hard base and 10 percent soft base.

Sulfur-Extended-Asphalt Emulsions. The anionic SS-15 and SS-30 SEA emulsions were produced by Petroleum Sciences, Inc. in a laboratory Charlotte Colloid Mill. No solvent was used in production of the SEA emulsions. The SEA emulsions do not meet Caltrans specifications for SS-1h emulsions for storage stability, 5 day settlement, and cement mixing and the SS-15 does not meet the viscosity requirement. Solubilities were not determined as sulfur is not soluble in trichlorethylene.

3.0 EXPERIMENTAL DESIGN AND DATA ANALYSIS

3.1 Asphalt Emulsions

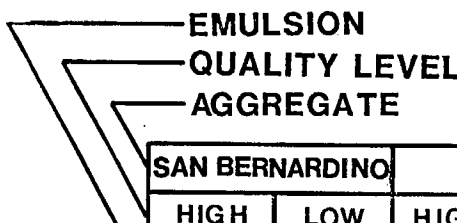
The experiment is designed as a completely randomized 3 by 2 by 3 cell fixed factorial model with two replications per cell. The experiment compares data for the CSS-0 and CMS-0 emulsions to those for mixtures containing the CMS-7 emulsion. The experimental factorial is shown in Figure 1. The model for analysis is:

$$Y_{ijkl} = \mu + A_i + Q_j + E_k + AQ_{ij} + AE_{ik} + QE_{jk} + AQE_{ijk} + \epsilon_{(ijk)l}$$

in which:

Y_{ijkl}	=	Response variable (density, stabilometer, etc.)
μ	=	Effect of the overall mean
A_i	=	Effect of aggregate type
Q_j	=	Effect of aggregate quality level
E_k	=	Effect of emulsion type
AQ_{ij}	=	Effect of aggregate-quality level interaction
AE_{ik}	=	Effect of aggregate-emulsion interaction
QE_{jk}	=	Effect of quality level-emulsion interaction
AQE_{ijk}	=	Effect of aggregate-quality level-emulsion interaction
ϵ_{ijkl}	=	Experimental error

The data were subjected to conventional three-way analysis of variance (ANOVA) techniques (7) and tested significance at the 95 and 99 percent confidence levels by the F-test (7). Following ANOVA, data were ranked by the Newman-Keuls means ranking procedure (8) at the 95 percent confidence level to identify significant differences in the data and to aid in interpretation.



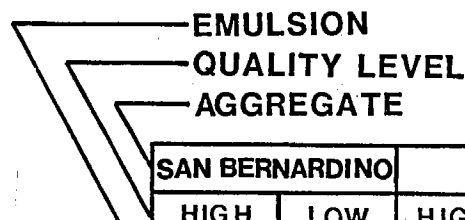
	SAN BERNARDINO		FRESNO		GRANITEROCK	
	HIGH	LOW	HIGH	LOW	HIGH	LOW
CSS0	—	—	—	—	—	—
CMS0	—	—	—	—	—	—
CMS7	—	—	—	—	—	—

Figure 1. Experimental Matrix, Asphalt Emulsions

Two complete mixture designs were performed at random for each emulsion-aggregate combination contained in the experimental matrix. Physical properties of mixtures at the design binder content from each mix design were analyzed. With several of the test procedures, three replications per cell were used instead of two in order to increase the power of the analysis.

3.2 Sulfur-Extended-Asphalt Emulsions

The sulfur-extended-asphalt emulsion experiment was designed essentially in the same manner as the asphalt emulsion experiment, except that for this experiment, data for the SS-15 and SS-30 percent SEA emulsions are compared to those for the CMS 7 emulsion. The experimental factorial for this experiment is shown in Figure 2. The experiment is sequentially randomized and uses data developed during the asphalt emulsion portion of the study for the CMS-7 emulsion and data developed using the SEA emulsions. The analytical model and analysis techniques are the same as used for the asphalt emulsion experiment.



	SAN BERNARDINO		FRESNO		GRANITEROCK	
	HIGH	LOW	HIGH	LOW	HIGH	LOW
S	—	—	—	—	—	—
S	—	—	—	—	—	—
15	—	—	—	—	—	—
S	—	—	—	—	—	—
S	—	—	—	—	—	—
30	—	—	—	—	—	—
C	—	—	—	—	—	—
M	—	—	—	—	—	—
S	—	—	—	—	—	—
7	—	—	—	—	—	—

Figure 2. Experimental Matrix,
Sulfur-Extended-Asphalt Emulsions

4.0 MIXTURE DESIGNS AND SPECIMEN TESTING

4.1 Introduction to Procedure

Currently, no standardized procedure for the mixture design of emulsified asphalt paving mixtures exists even though much work and considerable research has been performed on the subject (9). Presently, mixture design methods have been developed by The Asphalt Institute (3), U.S. Forest Service (10), Chevron (11), Federal Highway Administration (12) K. E. McConaughay, Inc. (32), University of Illinois (13), Purdue (14), ArmaK (15), University of Arizona (16), and University of Mississippi (17). Detailed reviews of procedures and requirements of these methods are available (9, 18).

The mixture design procedure used during this study generally follows that proposed by The Asphalt Institute in publication PCD-1 (3). Basically, the procedure consists of determining required moisture for proper coating, mechanically mixing emulsion and aggregate, loose curing the mixtures to obtain appropriate fluids content for optimum compaction, compacting the air cured mixture using light Hveem compaction followed by static double plunger leveling, and curing by dessicating to constant weight and modulus. Cured specimens were tested and analyzed according to methods designed for and used for determining properties of quality hot-mix asphalt concrete mixtures.

4.2 Testing Procedures During The Mixture Design Phase

When specimens reached the full cure condition, their properties and characteristics were analyzed using conventional Hveem mix design techniques. Density-voids relationships, stabilometer values, and cohesiometer values were determined. In addition, film stripping tests were performed. In several cases, slight modifications to the test procedures were required due to the use of emulsified asphalt mixtures. Testing procedures which were used are:

- Film stripping - Caltrans 302
- Bulk specific gravity - Caltrans 308

- Stabilometer - Caltrans 366
- Cohesimeter - Caltrans 306
- Maximum Theoretical Specific Gravity - ASTM D2041-78

4.3 Mixture Design Calculations

Following completion of the above tests, the density-voids characteristics of the specimens for each mix design were determined. The procedure used follows that outlined in The Asphalt Institute Manual MS-2 (19).

4.4 Selection of Design Emulsion Residue Content

Presently, no standardized method for selecting the design emulsion residue content for emulsified asphalt mixtures exists. For dense graded permanent surfaces, the PCD-1 manual (3) specifies a design binder content which gives a minimum of 75 percent aggregate coating, a minimum stabilometer value at 140F of 30, and a minimum cohesimeter value at 140F of 100. These criteria, however, are very general and not very restrictive. No requirements on air voids or voids in mineral aggregate are specified. Several other design methods specify minimum Marshall stability requirements, air voids, and stability losses due to soaking in water. So that meaningful comparisons can be made and so that appropriate conclusions can be drawn from the data developed in this study, design emulsion residue contents which are applicable for comparable mixtures made with hot-mix asphalt for each aggregate and quality level being investigated were selected considering air voids, V.M.A., and stabilometer value variations with emulsion residue content. Data for each aggregate at each quality level with the three asphalt emulsions were considered and a design residue content selected for each aggregate at each quality level.

Design emulsion residue contents selected for the six project aggregates are:

<u>San Bernardino</u>		<u>Fresno</u>		<u>Graniterock</u>	
<u>High</u>	<u>Low</u>	<u>High</u>	<u>Low</u>	<u>High</u>	<u>Low</u>
7.0%	7.5%	7.0%	7.5%	5.5%	6.0%

4.5 Tests on Specimens at the Design Residue Content

Following selection of the design residue contents, nine additional specimens at the design residue content for each aggregate-quality level-emulsion combination were mixed, compacted and desiccated until the full cure condition was reached. Three specimens of each mixture type were used for each of the following tests:

- Swell - Caltrans 305
- Moisture Vapor Susceptibility - Caltrans 307
- Surface Abrasion - Caltrans 360

5.0 CONCLUSIONS

Based on testing, mixture designs, and analyses performed with the materials studied during this investigation, several conclusions regarding the use of solvent free asphalt and sulfur-extended asphalt emulsions with aggregates from California may be drawn.

5.1 Solvent Free Asphalt Emulsions

1. Stable, solvent free cationic slow set and cationic medium set asphalt emulsions can be produced which meet Caltrans specifications for cationic emulsions.
2. Solvent free cationic asphalt emulsions can effectively coat aggregates with minus No. 200 mesh contents in excess of 10 percent and sand equivalent values as low as 15. Greater degrees of coating are obtained with solvent free cationic slow set emulsions than with solvent free cationic medium set emulsions.
3. In the laboratory and for the materials used in this study, greater degrees of compaction can be obtained using a conventional cationic medium set emulsion which contains 7 percent solvent than with solvent free asphalt emulsions.

4. Higher stabilometer values, cohesiometer values, and resilient moduli are obtained for laboratory mixtures containing low quality aggregates with the solvent free asphalt emulsions than with the emulsion containing solvent. This is believed due to the higher viscosity of the solvent free emulsion residues when compared to the residue from the emulsion containing solvent.
5. Laboratory specimens containing solvent free asphalt emulsions experience higher losses of stabilometer value after conditioning using the moisture vapor sensitivity procedure than specimens with the asphalt emulsion containing solvent. This effect, however, may be related to the lesser degrees of compaction attained when using the solvent free asphalt emulsions as compared to the emulsion containing solvent.
6. Laboratory specimens which contained the solvent free asphalt emulsions with lower quality aggregates experienced higher amounts of swell and greater surface abrasion losses than specimens with the emulsion containing solvent.
7. Due to the greater stiffness of mixtures containing the solvent free asphalt emulsions as compared to the solvent asphalt emulsion, lesser pavement thicknesses are required when using solvent free emulsions. It is noted that the pavement section design procedure used herein does not consider the moisture sensitivity of the materials which may be an important factor in field performance.
8. Most of the paving mixtures investigated which contained the low quality aggregates and the solvent free asphalt emulsions met stabilometer requirements for Caltrans Type C asphalt concrete. However, only three of the mixtures also met moisture vapor susceptibility and swell requirements. Mixtures which met these requirements were Fresno high quality aggregate with CSS-0 emulsion and Graniterock high quality aggregate with both CMS-0 and CMS-7 emulsion, and Graniterock high quality aggregate with CMS-7 emulsion.

9. The desirability of using solvent free aqueous emulsion asphalt concrete mixes for secondary road construction, in view of the positive and negative laboratory test results obtained for laboratory prepared and tested specimens, must remain a judgement of the highway construction engineer who must consider pollution abatement achievable through the use of emulsified asphalt systems and weigh this against other considerations as cost effectiveness and road durability among others.

5.2 Sulfur-Extended-Asphalt Emulsions

1. Stable solvent free water based anionic slow set emulsions using sulfur-extended-asphalt (SEA) base stocks can be produced which meet most Caltrans specifications for anionic slow set emulsions.
2. Anionic SEA emulsion can effectively coat both low and high quality aggregates.
3. Use of SEA emulsions resulted in higher resilient modulus values for both low and high quality aggregates than use of the emulsion containing solvent.
4. Mixtures containing the SEA emulsions had higher stabilometer values with low quality aggregates than mixtures with the emulsion containing solvent.
5. Specimens containing the SEA emulsion with low quality aggregates swelled to a greater extent and experienced higher surface abrasion losses than those with the emulsion containing solvent.
6. Specimens containing the SEA emulsions experience greater losses of stabilometer value after conditioning using the moisture vapor sensitivity procedure than specimens with the solvent asphalt emulsion indicating a greater sensitivity to moisture.

7. Due to the greater stiffness of mixtures containing the SEA emulsions as compared to the solvent asphalt emulsion, lesser pavement thicknesses would be required when using SEA emulsions. Again, it is noted that the pavement section design procedure used herein does not consider the moisture sensitivity of the materials.
8. All of the paving mixtures containing low quality aggregates and SEA emulsions studied met Caltrans stabilometer requirements (30 minimum) for Type C asphalt concrete, however, several mixtures did not meet swell and moisture vapor susceptibility requirements for Type C asphalt concrete. Mixtures containing the SEA emulsions which met swell requirements were Fresno high quality aggregate, Graniterock high quality aggregate, and Graniterock low quality aggregate with SS-15 SEA emulsion, and San Bernardino high quality aggregate, Fresno high quality aggregate, Fresno low quality aggregate, Graniterock high quality aggregate, and Graniterock low quality aggregate with SS-30 SEA emulsion. MVS conditioned stabilometer value requirements were met only by Fresno low quality aggregate and Graniterock high quality aggregate with the SS-15 SEA emulsion and Graniterock high quality with the SS-30 SEA emulsion.
9. The desirability of using solvent free aqueous emulsion asphalt concrete mixes for secondary road construction, in view of the positive and negative laboratory test results obtained for laboratory prepared and tested specimens, must remain a judgement of the highway construction engineer who must consider pollution abatement achievable through the use of emulsified asphalt systems and weigh this against other considerations as cost effectiveness and road durability among others.

6.0 RECOMMENDATIONS

- 6.1 This study has investigated the properties of paving mixtures containing several low quality aggregates and several types of emulsified binders. Test methods and criteria used to design and assess mixture characteristics were those specified for hot-mix asphalt concrete in California. An objective of the research study is to determine if solvent free emulsified binders can be used in place of cutback asphalt binders. Therefore, in order to permit drawing of appropriate conclusions from the data presented in this report on the effectiveness of the emulsions studied for replacing cutback asphalts, additional laboratory work is required. It is suggested that properties and characteristics of mixtures containing the project aggregates and cutback asphalts be determined. The study should evaluate the same properties considered in this study. Determination of mixture characteristics using cutback binders would permit direct comparisons between the cutback and emulsified binder systems and the drawing of more definite conclusions. Additionally, a study which would determine properties of mixtures containing hot-mixed asphalt cement would be of aid in evaluating results.
- 6.2 After completion of the additional laboratory studies, if results so indicate, it is recommended that several field experimental studies using aggregates ranging in quality from low to high with solvent free emulsified asphalt binders be undertaken. Projects should be constructed in several climatic regions in California (wet and arid) and should include control sections containing both cutback and, if possible, hot-mixed asphalts. Proper laboratory mixture designs, construction control, and field monitoring of results and performance should be used. Results of these experiments should provide indications of performance of the various mixtures in actual use.
- 6.3 Results of this study indicate that mixtures containing the SEA binders are detrimentally affected by moisture to a greater degree than with standard emulsions. However, performance of mixtures containing the SEA emulsions may be adequate in arid regions. Therefore, it is recommended that in order to further investigate the usefulness of paving mixtures containing the SEA emulsions, that field experimental test sections using the SEA emulsions be constructed and evaluated.

- 6.4 It is strongly suspected that the moisture vapor susceptibility of the solvent free asphalt emulsion mixes evaluated herein could be reduced by a slight modification of the emulsion formulations. This possibility should be evaluated.

References

1. Request For Proposals, "Investigation Into The Nature Of Emulsified Asphalts Compatible With California Local Aggregates And Substitution Of Sulfur For Asphalt In Aqueous Emulsified Systems," California Air Resource Board, Research Division, Sacramento, California, March, 1980.
2. American Society for Testing and Materials, 1981. Annual Book of Standards, Part 15, Road, Paving, Bituminous Materials; Traveled Surface Characteristics, Philadelphia, PA, 1981.
3. "Interim Guide to Full-Depth Asphalt Paving Using Various Asphalt Mixes," The Asphalt Institute, Pacific Coast Division, PCD-1, January, 1976.
4. Kennepahl, G.J.A., Logan, A., and Bean, D. C., "'Conventional' Paving Mixes with Sulfur-Asphalt Binders," Proceedings AAPT, Volume 44, 1975.
5. Deme, Imants, "Processing of Sand-Asphalt-Sulfur Mixes," Proceedings AAPT, Volume 43, 1974.
6. Rosner, J. C. and Chehovits, J. G., "Highway Binder Materials From Modified Sulfur-Water Emulsions," Report No. FHWA/RD-82/035, Federal Highway Administration, November, 1981.
7. Applied Linear Statistical Models, Neter, I. and Wasserman, W., Richard D. Irwin, Inc., Homewood, Illinois, 1974.
8. Applied Statistical Methods, Burr, I. W., Academic Press, Inc., New York, 1974.
9. Waller, F. H., Jr., "Emulsion Mix Design Methods: An Overview," Transportation Research Record 754, 1980.
10. "Design of Dense-Graded Emulsified Asphalt Mixtures," Report R6-350(74), U.S. Forest Service, 1974.
11. Bitumils Mix Manual, Chevron, U.S.A., Asphalt Division, January, 1977.

12. "Mix Design Procedure For Dense-Graded Emulsified Asphalt Pavement," FHWA Region 10, Office of Federal Highway Projects.
13. Darter, M. I., Ahlfield, S. R., Wilky, P. L., and Wasill, R. G., "Development of Emulsified Asphalt Aggregate Cold Mix Design Procedure," Research Report 505-5, Department of Civil Engineering, University of Illinois, 1978.
14. A. A. Gadallah, L. E. Wood, and E. J. Yoder, "A Suggested Method for the Preparation and Testing of Asphalt-Emulsion-Treated Mixtures Using Marshall Equipment," Proceedings AAPT, Volume 46, 1977.
15. "Marshall Stability," Highway Chemicals Department, Armak Company, McCook, Illinois.
16. Jiminez, R. A., "Final Report-Phase I, Asphalt Emulsion Treated Aggregates," University of Arizona, Research Report HPR-1-13(150), January, 1977.
17. George, K. P., "Interim Report on Criteria for Emulsified Asphalt Stabilization of Sandy Soils," University of Mississippi for Mississippi State Highway Department, October, 1976.
18. Fong, G. K., "Mix Design Methods for Base and Surface Courses Using Emulsified Asphalt A State-of-the-Art Report," Report No. FHWA-RD-78-113, Federal Highway Administration, October, 1978.
19. Mix Design Methods for Asphalt Concrete, Manual Series No. 2 (MS-2), The Asphalt Institute, March, 1979.